

10/052,347
FUJIT.020CONT

REMARKS

Claims 19-52 and 119-127 are all the claims presently pending in the application. Claims 19-24 and 119-121 have been amended to more particularly define the invention. Attached hereto is a marked-up version of the changes made to the claims by the current Amendment.

It is noted that the claim amendments are made only for more particularly pointing out the invention, and not for distinguishing the invention over the prior art, narrowing the claims or for any statutory requirements of patentability. Further, Applicant specifically states that no amendment to any claim herein should be construed as a disclaimer of any interest in or right to an equivalent of any element or feature of the amended claim.

Claims 19-36 and 119-121 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Sayyah ("A Study of Growth Mechanisms and Electrical and Optical Properties of Epitaxial $\text{Al}_x\text{Ga}_{1-x}\text{N}$ Layers Grown by Atmospheric Pressure Metalorganic Chemical Vapor Deposition", A Dissertation Presented to the Faculty of the Graduate School, University of Southern California, February 1986) Claims 37-52 and 122-127 stand rejected under 35 U.S.C. § 103(a) as being unpatentable over Sayyah.

These rejections are respectfully traversed in view of the following discussion.

I. THE CLAIMED INVENTION

The claimed invention (e.g., as recited in claim 19) is directed to a method for producing a gallium nitride group compound semiconductor by using an organometallic compound vapor phase epitaxy. The inventive method includes setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity of the gallium nitride group compound semiconductor increases substantially proportionally with the mixing ratio so as to obtain a desired conductivity (1/resistivity) of the gallium nitride group compound semiconductor, and forming the gallium nitride group compound semiconductor by feeding the silicon-containing gas and the at least one other raw material gas at the mixing ratio.

10/052,347
FUJIT.020CONT

In another aspect (e.g., as recited in claim 20), the inventive method includes setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a carrier concentration of the gallium nitride group compound semiconductor increases substantially proportionally with the mixing ratio so as to obtain a desired carrier concentration of the gallium nitride group compound semiconductor, and forming the gallium nitride group compound semiconductor by feeding the silicon-containing gas and the at least one other raw material gas at the mixing ratio.

Conventional methods do not set a mixing ratio of a silicon-containing gas to at least one other raw material gas during the vapor phase epitaxy at a desired value in a range over which conductivity (e.g., carrier concentration) of the gallium nitride group compound semiconductor increases substantially proportionally with the mixing ratio. Therefore, the conductivity (e.g., carrier concentration) is not easily controlled.

The claimed method, on the other hand, includes setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity (e.g., carrier concentration) of the gallium nitride group compound semiconductor increases substantially proportionally with the mixing ratio.

The inventive method enables a production of a gas-phase grown GaN layer of high purity. That is, it provides an n-type GaN layer with high resistivity without requiring a doping with impurities, unlike conventional technology which provides n-type GaN with low resistivity when no doping is performed.

III. THE SAYYAH REFERENCE

The Examiner alleges that Sayyah teaches the invention as recited in claims 19-36 and 119-121, and makes obvious the invention as recited in claims 37-52 and 122-127. Applicant submits, however, that there are elements of the claimed invention that are not taught or suggested by Sayyah.

Sayyah discloses factors influencing the properties of epitaxial layers of $\text{Al}_x\text{Ga}_{1-x}\text{N}$ grown on sapphire substrates by the atmospheric pressure metallorganic chemical vapor deposition (MOCVD) technique (Sayyah at page 162).

10/052,347
FUJIT.020CONT

However, Applicant submits that Sayyah does not teach or suggest a method for producing a gallium nitride group compound semiconductor by an organometallic compound vapor phase epitaxy, where the method includes setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity (e.g., carrier concentration) of the gallium nitride group compound semiconductor increases substantially proportionally with the mixing ratio, as claimed, for example, in claims 19-20.

As noted above, conventional methods do not set a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which conductivity/carrier concentration) increases substantially proportionally with the mixing ratio. Therefore, the conductivity (e.g., carrier concentration) is not easily controlled. (Application at page 3, lines 2-12).

The claimed method, on the other hand, includes setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity/carrier concentration increases substantially proportionally with the mixing ratio. (Application at page 11, lines 3-11). The inventive method enables a production of a gas-phase grown GaN layer of high purity. That is, it provides an n-type GaN layer with high resistivity without requiring a doping with impurities, unlike conventional technology which provides n-type GaN with low resistivity when no doping is performed (Application at page 3, lines 6-12).

As explained in the Application, the inventors have established a technology for a vapor phase epitaxy of a GaN semiconductor with an organometallic compound. Unlike conventional methods, in the inventive method a layer conductivity (e.g., carrier concentration) may be increased by increasing a ratio of silicon to at least one other raw material gas (e.g., trimethyl gallium (TMG) containing H₂, or NH₃) being supplied to a reactor.

This is clearly illustrated, for example, by Example 4, which is discussed in the Application at page 28, lines 2-14 and Figure 26. Moreover, as shown in Figure 26, the conductivity (e.g., carrier concentration) increases (e.g., linearly and steeply) as this mixing

10/052,347
FUJIT.020CONT

ratio is increased. Further, Applicant notes that an electron concentration increasing linearly is disclosed, for example, in U. S. Patent Nos. 6,472,690, 6,472,689 and allowed U. S. Patent Application No. 09/677,788 which are commonly assigned with the present Application.

Clearly, the Sayyah reference does not teach or suggest these novel features. Indeed, Applicant respectfully submits that at the time of this invention, it was commonly accepted that silicon was an acceptor impurity and could not be implanted in a layer to increase the conductivity of the layer, but instead would decrease the conductivity of the layer.

As evidence of this conventional belief, Applicant again directs the Examiner's attention to Khan (U. S. Pat. No. 4,614,961) which discloses that when a silicon concentration in AlGaIn is increased, the conductivity of AlGaIn cannot increase, Pankove et al. ("Optical Absorption of GaN", Applied Physics Letters, Vol. 17, No. 5, September 1970, pp. 197-198), which shows that electron concentration decreases by doping silicon in GaN (page 198, upper left column, lines 2-3), and Tietjen et al. ("Vapor Phase Growth Technique and System for Several III-V Compound Semiconductors", March 1969, Electronics Research Center Cambridge, Massachusetts National Aeronautics and Space Administration), which shows that by doping silicon to undoped GaN, the electron concentration of GaN decreases to a range of $2.0 \times 10^{19}/\text{cm}^3$ to $3.0 \times 10^{16}/\text{cm}^3$ (e.g., Tietjen at Table II of page 4).

Further, contrary to the Examiner's allegations, Sayyah does not teach or suggest setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity/carrier concentration increases substantially proportionally with the mixing ratio.

In sum, Sayyah does not aim to increase electron concentration by doping silicon. Instead, Sayyah merely shows that composition ratios of Al and Ga in an AlGaIn layer may be varied by using silane.

Further, Sayyah fails to control electron concentration. In short, Sayyah cannot increase electron concentration. Indeed, it is important to understand that involving Si in an AlGaIn layer is completely different from increasing electron concentration. That is, there is no causal relationship between the two processes. Thus, in Sayyah's invention, even when Si

is included in AlGa_N, electrons are not excited by that Si to the conduction band of the AlGa_N.

On the contrary, in the claimed invention, Si excites electrons to the conduction band of AlGa_N, and electron concentration increases as the ratio of a gas containing Si to a gas containing other material increases. This is clearly different from Sayyah, which may disclose a silicon concentration in a semiconductor layer, but fails to disclose an electron concentration which is controlled when silicon is doped into the semiconductor layer. In fact, electron concentration is not disclosed or suggested in Sayyah, likely because Sayyah could not control electron concentration.

More specifically, Applicant notes that at the time of the claimed invention, no conventional technology could effectively control electron concentration even by doping silicon.

Further, Sayyah may disclose doping silicon in GaN as alleged by the Examiner, but Sayyah clearly fails to teach or suggest that such doping causes an increase in conductivity and electron (e.g., carrier) concentration as shown, for example, in Figure 25 of the present invention. Moreover, at the time when the present invention was invented, it had not been known that Si is a donor which excites electrons and that electron concentration may be controlled linearly by Si concentration, as shown in Figure 26 of the present invention.

In Sayyah, it is clearly shown that even when silicon is doped in Al_xGa_{1-x}N to a doping concentration of $8 \times 10^{21}/\text{cm}^3$, the conductivity of Al_xGa_{1-x}N cannot be changed. It is further disclosed that even if silicon is doped in Al_xGa_{1-x}N having a comparatively high molar fraction of aluminum, a conductivity of a film was not changed from semi-insulative to conductive (Sayyah at page 135, lines 18-20). It is also disclosed that when $1.4 \times 10^{21}\text{cm}^{-3}$ and $8.0 \times 10^{21}\text{cm}^{-3}$ of silicon were doped in Al_xGa_{1-x}N having aluminum composition ratio x of 0.56 and 0.81, respectively, any measurable conductivity cannot be observed (Sayyah at page 135, lines 20-22). This is clearly contrary to the present method in which electron concentration substantially linearly increases with an increase in the amount silicon doping, (Application at Figure 26). Thus means that silicon functions as donor impurity in the present invention.

10/052,347
FUJIT.020CONT

In addition, Sayyah may disclose that SiH_4 / (TMG + TMA) ratio is in a range of 0 to 0.1 (Sayyah at Figure 27). However, Sayyah clearly does not teach or suggest setting this ratio in a range over which a conductivity/carrier concentration increases substantially proportionally with the mixing ratio. Instead, Sayyah only teaches that uptake quantity of Ga and Al varies according to a doping quantity of Si (Sayyah at page 129, lines 2-5).

Further, the Examiner states that Sayyah discloses “flow rate of silane is 10-1200 SCCM to obtain donor concentration of $9 \times 10^{18} / \text{cm}^3$ ”. However, this is not correct. Presumably, the Examiner is referring to the passage at page 116, lines 6-14 to support her position. However, this passage merely states that the minimum detectability limit (MDL) of silicon is $9 \times 10^{18} / \text{cm}^3$. In other words, this value is merely used to describe the sensitivity of the silicon detecting equipment used by Sayyah (e.g., see Sayyah at Figure 32). This passage does not suggest that this was the amount of the silicon detected, as alleged by the Examiner. Indeed, the passage goes on to state that “no silicon was detected in any of the as grown $\text{Al}_x\text{Ga}_{1-x}\text{N}$ samples” (Sayyah at page 116, lines 12-14) (emphasis Applicant’s).

Moreover, Applicant notes that if silicon is doped into AlGaIn, the silicon never excites electrons in its conduction band. Accordingly, in Sayyah’s invention, silicon does not function to excite electrons in the conduction band. In short, Sayyah cannot increase electron concentration by doping silicon.

In addition, the Examiner concedes that Sayyah does not teach or suggest the carrier concentration or conductivity of the layer, but states that the “electron concentration is close to that of disclosed silicon concentration”. First, as noted above, Sayyah reports that even significant silicon doping (e.g., $8 \times 10^{21} \text{ cm}^{-3}$) failed to result in “any measurable conductivity” (Sayyah at page 135, lines 20-22). Therefore, Sayyah would appear to contradict the Examiner’s reasoning.

Moreover, in the claimed invention, the mixing ratio may be set to a value in a range over which a conductivity/carrier concentration increases substantially proportionally with the mixing ratio. However, the Sayyah method clearly does not include setting such a mixing ratio (e.g., see Sayyah at Figure 28).

10/052,347
FUJIT.020CONT

Therefore, Sayyah does not disclose a carrier concentration comparable to that disclosed by the present application (e.g., about $1 \times 10^{17}/\text{cm}^3$ to $1 \times 10^{19}/\text{cm}^3$), and Sayyah clearly does not teach or suggest setting a mixing ratio of a silicon-containing gas to at least one other raw material gas at a desired value in a range over which a conductivity/carrier concentration increases substantially proportionally with the mixing ratio so as to obtain a desired conductivity/carrier concentration.

Therefore, Applicant submits that Sayyah does not teach or suggest each and every element of the claimed invention. Therefore, the Examiner is respectfully requested to withdraw this rejection.

III. FORMAL MATTERS AND CONCLUSION

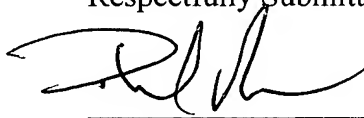
In view of the foregoing, Applicant submits that claims 19-52 and 119-127 all the claims presently pending in the application, are patentably distinct over the prior art of record and are in condition for allowance. The Examiner is respectfully requested to pass the above application to issue at the earliest possible time.

Should the Examiner find the application to be other than in condition for allowance, the Examiner is requested to contact the undersigned at the local telephone number listed below to discuss any other changes deemed necessary in a telephonic or personal interview.

The Commissioner is hereby authorized to charge any deficiency in fees or to credit any overpayment in fees to Attorney's Deposit Account No. 50-0481.

Respectfully Submitted,

Date: 3/19/03



Phillip E. Miller
Reg. No. 46,060

McGinn & Gibb, PLLC
8321 Old Courthouse Road, Suite 200
Vienna, VA 22182-3817
(703) 761-4100
Customer No. 21254

10/052,347
FUJIT.020CONT

VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE CLAIMS:

Please amend the claims to read as follows:

19. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by using an organometallic compound vapor phase epitaxy, comprising:

setting a mixing ratio of a silicon-containing gas to at least one [and] other raw material gas [gases] during said vapor phase epitaxy at a desired value in a range over which a conductivity of the gallium nitride group compound semiconductor increases substantially proportionally with said mixing ratio so as to obtain a desired conductivity (1/resistivity) of said gallium nitride group compound semiconductor; and

forming said gallium nitride group compound semiconductor by feeding said silicon-containing gas and said at least one other raw material gas [gases] at said [a] mixing ratio [set above].

20. (Twice Amended) A method for producing a gallium nitride group compound semiconductor by using an organometallic compound vapor phase epitaxy, comprising:

setting a mixing ratio of a silicon-containing gas to at least one [and] other raw material gas [gases] during said vapor phase epitaxy at a desired value in a range over which a carrier concentration of the gallium nitride group compound semiconductor increases substantially proportionally with said mixing ratio so as to obtain a desired carrier concentration of said gallium nitride group compound semiconductor; and

forming said gallium nitride group compound semiconductor by feeding said silicon-containing gas and said at least one other raw material gas [gases] at said [a] mixing ratio [set above].

21. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 19, wherein said gallium nitride group compound semiconductor comprises [is] $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ($0 \leq x \leq 1$).

10/052,347
FUJIT.020CONT

22. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 20, wherein said gallium nitride group compound semiconductor comprises [is] $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ($0 \leq x \leq 1$).

23. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 19, wherein said gallium nitride group compound semiconductor comprises [is] GaN.

24. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 20, wherein said gallium nitride group compound semiconductor comprises [is] GaN.

119. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 20, wherein said carrier [electron] concentration ranges from $1 \times 10^{17}/\text{cm}^3$ to $1 \times 10^{19}/\text{cm}^3$.

120. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 22, wherein said carrier [electron] concentration ranges from $1 \times 10^{17}/\text{cm}^3$ to $1 \times 10^{19}/\text{cm}^3$.

121. (Amended) A method for producing a gallium nitride group compound semiconductor according to claim 24, wherein said carrier [electron] concentration ranges from $1 \times 10^{17}/\text{cm}^3$ to $1 \times 10^{19}/\text{cm}^3$.